Liquefaction Hazards for the Smithfield Quadrangle, Central Cache Valley, Utah

by

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2001

Research supported by U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 1434-HQ-98-GR-00024. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

UTAH GEOLOGICAL SURVEY

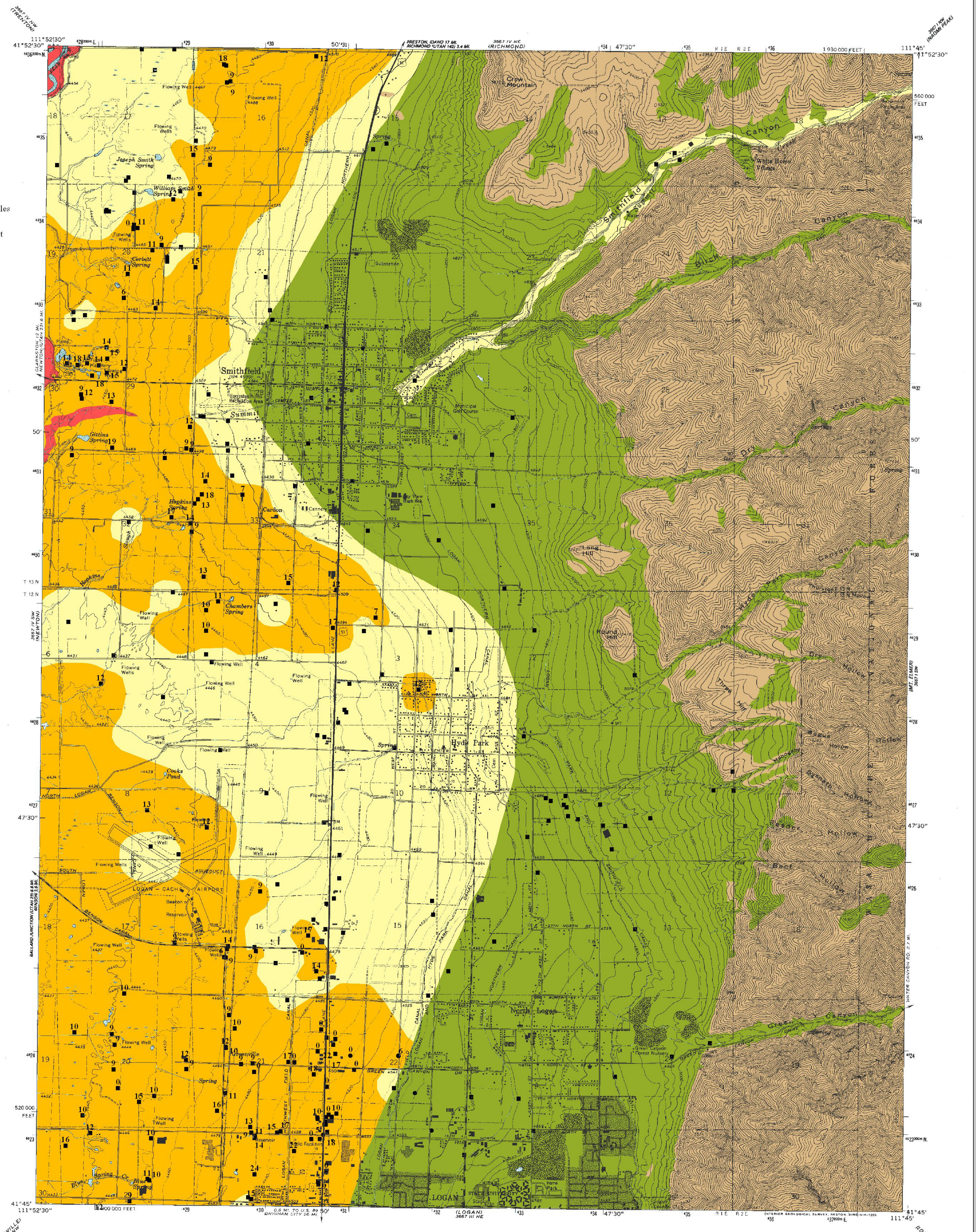
Contour Interval 40 Feet

Scale 1:24,000

1 0 1 2 Miles

5,000 0 5,000 10,000 Feet

1 0 1 2 Kilometers



Sources of Subsurface Data

- 12 ● Geotechnical borehole with data to 15-meter depth, showing liquefaction value ranging from 0 to 25 in moderate-hazard areas
- ○ Geotechnical borehole with insufficient data to classify
- 12 ■ Water well with data to 15-meter depth, showing liquefaction value ranging from 0 to 25 in moderate-hazard areas
- □ Water well with insufficient data to classify
- Shallow excavation (generally less than 3 meters deep) with insufficient data to classify

DISCUSSION

Liquefaction occurs during earthquakes when shallow, water-saturated, cohesionless soils are subjected to ground shaking. Cohesionless soils are generally sandy, with little clay, although some silty and gravelly soils are vulnerable to liquefaction. Upon liquefaction, susceptible soils lose their strength and ability to withstand the weight of overlying sediments and structures. Liquefaction is one of the major causes of earthquake damage. During the August 30, 1962, earthquake in Cache Valley (magnitude 5.7), liquefaction occurred along the banks of the Bear River near Trenton (about 25 kilometers northwest of Logan) when liquefied sand was extruded from cracks and sand boils (Hill, 1979).

This map estimates the liquefaction hazard by: (1) showing areas in which the potential for liquefaction is increased due to the presence of susceptible soils, and (2) relating the susceptibility to the intensity, probability, and frequency of earthquake ground shaking required to induce liquefaction. Ground motions for each mapped hazard rating are shown in table 1. See plate 3 for estimation of the effects of liquefaction-induced lateral-spreading slope failures.

This map was compiled by first collecting relevant surficial-geologic and subsurface data and then integrating the data into a Geographic Information Systems (GIS) format using ArcView GIS v3.2 (Environmental Systems Research Institute, Inc., 1999) and ArcView Spatial Analyst v2.0a (Environmental Systems Research Institute, Inc., 2000) software. Surficial-geologic data include the distribution of unconsolidated and bedrock units (McCalpin, 1989; Lowe and Galloway, 1993; Evans and others, 1996; Solomon, 1999) and geologic units which experienced liquefaction during the 1962 Cache Valley earthquake (Hill, 1979). Subsurface data are related to factors listed by Obermeier (1996) as contributing to liquefaction: (1) grain size, (2) relative density, (3) depth and thickness of strata, (4) age of sediments, (5) characteristics of the overlying confining bed, (6) topography and the nature of seismic shaking, (7) depth to ground water, and (8) seismic history. Of these eight factors, we do not consider three (age, topography, and seismic history) because they are essentially constant throughout the central Cache Valley. We estimate depth to ground water from the study of ground-water resources of Cache Valley by Bjorklund and McGreevy (1971).

Although liquefaction may occur at depths greater than 20 meters, soil deeper than 15 meters is commonly too deep to liquefy (Seed, 1979). Only 43 of 182 geotechnical boreholes in the central Cache Valley are at least 15 meters deep, and most of these are clustered in Logan. In contrast to the limited depth and irregular spatial distribution of geotechnical boreholes, water wells in the area are typically deeper than 15 meters and are widely and uniformly distributed. Of 1,032 water wells in the area, 1,014 are at least 15 meters deep. Therefore, we use both geotechnical-borehole and water-well logs to obtain information on the remaining four factors within the upper 15 meters of soil. Numerical values are assigned to variables related to the factors, the values are summed for each liquefiable layer, and the layer with the highest sum (liquefaction value) is assumed to represent the liquefaction potential at the site. Our map shows liquefaction values for boreholes and wells in moderate-hazard areas to indicate the relative susceptibility of soil to liquefaction. Areas with lower hazard ratings generally lack susceptible soils or have deep ground water. Areas with a high hazard rating have experienced historical liquefaction and are not defined by liquefaction values (table 1).

- Although water wells are more widespread than geotechnical boreholes, geologic interpretations based on water-well logs are less precise than interpretations of borehole logs. The use of water-well logs is appropriate only for regional studies in areas where geotechnical data are sparse or lacking. Water-well logs should not be relied upon for site-specific investigations (table 2).

This map is the third generation of mapping regional liquefaction hazards in the central Cache Valley. Hill (1979) first mapped liquefaction potential using a procedure developed by Youd and Perkins (1978) for liquefaction potential mapping in California based on geologic data. However, that procedure correlates liquefaction susceptibility with the age of surficial deposits. Anderson and others (1990) note that most deposits in the central Cache Valley are late Pleistocene and therefore are not sufficiently differentiated to determine liquefaction susceptibility based on age. They further observe that the internally drained basin in which Cache Valley lies preserved high liquefaction susceptibility in sediments of Pleistocene age that, in coastal areas of California studied by Youd and Perkins (1978), would have moderate to low liquefaction susceptibility. Anderson and others (1990) mapped liquefaction potential using engineering data to calculate cyclic stress ratios with relationships developed by Seed (1979). Critical accelerations required to initiate liquefaction were then obtained from the cyclic stress ratios, applied to regional seismicity to determine exceedance probabilities, and used with geology and topography to determine liquefaction potential zones. Our technique enables us to map a pattern of liquefaction potential similar to that mapped by Anderson and others (1990). However, Anderson and others (1990) map liquefaction potential by comparing the critical accelerations to the geologic and topographic settings of the limited areas where geotechnical data were analyzed and mapping liquefaction potential in areas with no geotechnical data using the correlation between geology, topography, and critical acceleration. We provide surrogate subsurface information in areas with no geotechnical data by interpreting abundant water-well logs. Our technique is thus independent of local surficial geology and reflects subsurface changes in soil conditions based on information from water wells.

This map is intended primarily for regional planning purposes and should not be used as a substitute for site-specific geotechnical investigations conducted by qualified professionals. The map is not intended for use at scales other than the published scale. Map boundaries are based on limited data available prior to the date of publication, are approximate, and are subject to change as the quantity and quality of available data improves. The liquefaction hazard at any particular site may actually be higher or lower than shown because of geological variations within a hazard rating, gradational and approximate map boundaries, and the regional scale of this map.

This map does not address man-made alterations to ground conditions (fill) because they could not be distinguished on a regional basis with the data available. The properties of fills vary from dense, engineered fills with a very low liquefaction susceptibility to loose fills with a very high liquefaction susceptibility. The use of fill may increase or decrease the hazard at a site.

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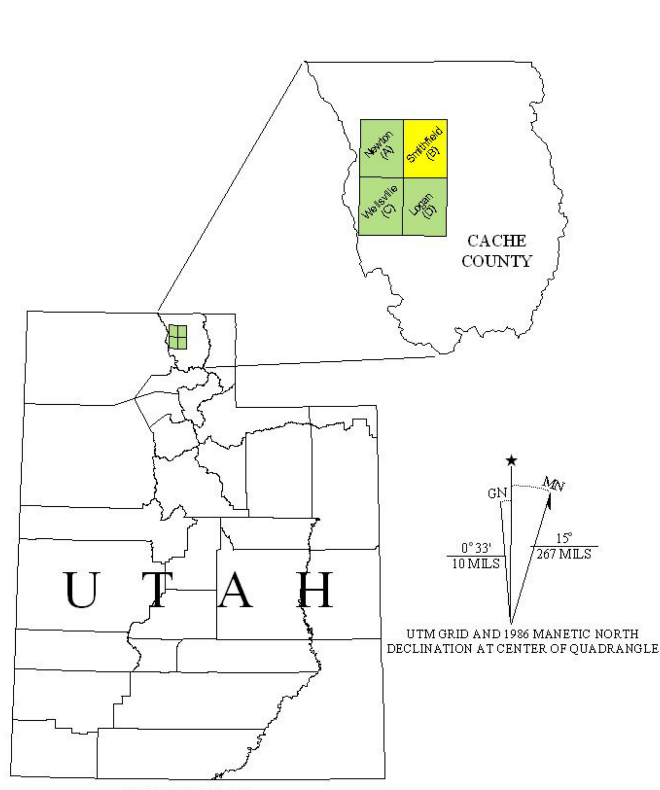

INDEX MAP

Table 1. Characteristics of liquefaction-hazard classifications in the central Cache Valley, Utah.

Liquefaction Hazard Rating	Hazard Rating Criteria				Ground Acceleration Required to Induce Liquefaction[4]			Predominant Geology[7]
	Historical Liquefaction[1]	Consolidation (compaction and cementation)	Depth to Ground Water (m)[2]	Liquefaction Value[3]	Equivalent Critical Acceleration (g)[5]	Approximate 50-Year Exceedance Probability (%)[6]	Ground-Motion Return Period (yrs)[6]	
High	Yes	No	<15	n.a.	<0.14	>20	<250	Holocene flood-plain deposits.
Moderate	No	No	<15	>5	0.14-0.28	5-20	250-1,000	Alluvial levee deposits and Lake Bonneville deposits with granular interbeds; shallow ground-water depth.
Low	No	No	<15	<5	0.28-0.41	2-5	1,000-2,500	Lake bottom deposits of Lake Bonneville and coarser-grained beds; moderate ground-water depth.
Very Low	No	No	>15	n.a.	>0.41	<2	>2,500	Unconsolidated deposits; deep ground water.
Not Susceptible	No	Yes	n.a.	n.a.	n.a.	n.a.	n.a.	Bedrock.

[1] Sites experiencing liquefaction during the 1962 Cache Valley earthquake are documented in Hill (1979).
[2] Bjorklund and McGreevy (1971).
[3] Areas of moderate and low liquefaction hazard include isolated wells with liquefaction values different than the rating criteria due to the smoothing effect of the GIS interpolation procedure.
[4] Liquefaction is induced in areas with higher liquefaction hazard ratings by lower levels of ground shaking (critical acceleration); lower levels of ground shaking are more likely to occur than are higher levels (exceedance probability) and thus occur more often (return period).
[5] Critical accelerations used by Anderson and others (1990) to define hazard-rating boundaries were calculated from borehole geotechnical data. Our equivalent critical accelerations are derived from maximum considered earthquake peak accelerations mapped by Frankel and others (1997) at the center of our four-quadrangle study area. Ground-motion return periods used to define hazard-rating boundaries are similar to those of Anderson and others (1990).
[6] Ground-motion return periods were chosen to approximate arbitrary values of exceedance probability selected by Anderson and others (1990), who used a 100-year time period to determine exceedance probability. For consistency with USGS national seismic-hazard maps (Frankel and others, 1997) we use a 50-year time period.
[7] Boundaries of hazard areas do not coincide with geologic map units except for the high-hazard area, which includes geologic units known to have experienced liquefaction during historical earthquakes.
n.a.–not applicable.

Table 2. Recommended requirements for site-specific investigations of mapped potential hazards.

Hazard	Soil Profile Type, Special-Study Area, or Potential-Hazard Area	Development Type: Essential Facilities, Special- and High-Occupancy Buildings	Industrial and Commercial Buildings (Other Than High-Occupancy)	Residential Subdivisions	Residential Single Lots
Amplified Ground Motion (Plate 1)	S_A, S_B	No	No	No	No
	S_C, S_D, S_E	Yes	Yes	No	No
	S_F	Yes	Yes	Yes	Yes
Surface Fault Rupture (Plate 1)	Inside Special-Study Area: Holocene Fault	Yes	Yes	Yes	Yes
	Inside Special-Study Area: Quaternary Fault	Yes	No[1]	No[1]	No[1]
	Outside Special Study Area	Yes	No	No	No
Liquefaction (Plate 2)	High, Moderate	Yes	Yes	No[2]	No[2]
	Low, Very Low	Yes	No	No	No
	Not Susceptible	No	No	No	No
Slope Failure[3] (Plate 3)	Very High, High, Moderate	Yes	Yes	Yes	Yes
	Low, Very Low	Yes	No	No	No

[1] At a minimum, appropriate disclosure should be required.
[2] At a minimum, appropriate disclosure should be required. If a site is also within an area with high or moderate potential for lateral spreading (earthquake-induced slope failure caused by liquefaction on shallow slopes; see plate 3), a site-specific investigation is advised consistent with recommendations for slope-failure hazards.
[3] If permanent cuts have slopes steeper than 2H:1V (50 percent) and are not supported by retaining walls, cut slope stability must be addressed in accordance with the Uniform Building Code (International Conference of Building Officials, 1997, Appendix Chapter 33, section 3312).

Maps in this report:
- Amplified Earthquake Ground-Motion and Surface-Fault-Rupture Hazards (Plates 1A-1D)
- Liquefaction Hazards (Plates 2A-2D)
- Earthquake-Induced Slope-Failure Hazards (Plates 3A-3D)